Renewable and Sustainable Energy Reviews 16 (2012) 4379–4384

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Liquid biofuels potential and outlook in Iran

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ARTICLE INFO

Article history:
Received 13 August 2011
Received in revised form
5 May 2012
Accepted 5 May 2012
Available online 21 June 2012

Keywords:
Liquid fossil fuels
Liquid biofuels
Biodiesel
Bioethanol

ABSTRACT

Iran's diversity of terrain and climate enables cultivation of a variety of energy crops suitable for liquid biofuels production. In Iran, the easily and readily available biofuel feedstock today for production of bioethanol is molasses from sugar cane and sugar beet. There is also about 17.86 million tons of crops waste from which nearly 5 billion liters of bioethanol could be produced annually. This amount of bioethanol is sufficient to carry out E10 for spark ignition engine vehicles in Iran by 2026. There is also enormous potential for cultivation of energy plants such as cellulosic materials and algae. Iran has 7% of its area covered with forest products which are suitable sources for liquid biofuels such bioethanol and biodiesel. Iran also has a long tradition of fishing in Caspian Sea and Persian Gulf with about 3200 km coastline and on inland rivers. The produced fish oil and other plant oils such as palm tree, jatropha, castor plant and algae are suitable biodiesel feedstock. Out of 1.5 million tons of edible cooking oil consumed in Iran annually, about 20% of it can be considered as waste, which is suitable biodiesel feedstock.This quantity along with the other possible potential feedstock are favorable sources to carry out B10 step by step until 2026.

Contents

1. Introduction

The outlook of liquid biofuels for transportation in Iran which is also called agrofuel, is the main focus of this paper. The strong interest in liquid biofuel is due to the fact that it can be used as a supplement, or alternative, to gasoline or diesel fuel derived from petroleum fossil fuel. It is the liquid biofuels easy use for transportation which generates the strong interest and tremendous increase in investments throughout the world. Biofuel can be processed and used in a variety of ways. Basically bioenergy in all of its forms, is energy produced from biomass including forest and agricultural plants. It can be harnessed from biomass in several ways and processed and used in solid, liquid or gaseous forms. In this paper only the liquid biofuel is considered which is mainly produced as ethanol or biodiesel. The feedstock for ethanol are mainly sugar cane and maize, and to a lesser extent from wheat, sugar beet and cassava.The feedstock for biodiesel are oil-producing crops, such as rapeseed, palm oil, algae and jatropha and also animal fats.

Fossil fuels provide the major energy needs of the world today. There are three main types of fossil fuels, namely oil, natural gas and coal. Fossil fuels provide around 66% of the world's electrical power, and 95% of the world's total energy demands including heating, transportation, electricity generation and other uses. Oil provides around 40% of energy, natural gases provide about 20% and coal provides 28%. A concern is that, the fossil fuel is being used up at an increasing rate, and that they will soon run out. If these fossil fuels were to run out now, there would not be a suitable replacement for them that is equally as efficient at producing the amount of energy. As the world is becoming more advanced in technology, more energy is being consumed to keep up with the changing requirements. At the current rate at which

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1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.05.013

energy is being consumed, the world will shortly come to an end of fossil fuels- the world's primary energy resource. Ever since that first oil well punched into the earth in the United States in 1859, demand for crude oil has equaled supply. The more oil that was pumped worldwide, the more got used. Most of the planet's current population of about7 billions people prefer the industrialized life-style. Also, most are now dependent on fossil-fueled agriculture to eat [1–6].

Progress has brought blessings and also problems. The world now uses 2268,000 t of petro-derived pesticides per year. Burning of fossil fuels is causing warmer weather, as carbon dioxide locked into the plant tissue eons ago is released back into the atmosphere. In 1892, Svante Arrhenius, a Swedish chemist, figured out that burning fossil fuels would cause global warming. He published a description of this greenhouse effect in 1896. Until recently, his work was ignored, criticized, or denied. Global warming could eventually result in global cooling too [7–11].

On the other hand, of all the problems generated by fossil fuel use, the most challenging will be surviving the withdrawal from that use, after worldwide oil production peaks and then begins to decline. The oil crisis will begin when demand for oil consistently begins to exceed supply. Hubbert, an American oil scientist warned that crisis would begin right after the peak of world production is reached-not when the last drop of oil is pumped. After the peak, demand and supply can no longer match. The long-term trend of rising demand will collide with a perpetually shrinking supply [12–17].

2. World oil production and reserve

The transition from petro-technology back to non-petro-technology, and its accompanying labor-intensive and materially-poor life, will begin after world oil production peaks. Presently the world's favorable petroleum geology is unequally divided up among some 182 nations, of which the top 42 produce more than 98% of the world's oil; the next 70 nations less than 2%; and the remaining nations 70, none [18–20].

Previous investigators have drawn curves for the years 1960–2040. The years 1960–1997 are historic data while the years 1998–2040 are forecasts using World Oil Forecasting Program World production peak is in 2006. The production of the 42 top nations was 3051.1 Gl/year in 1997 and it was forecast to peak in 2006 at 3637.85 Gl/year, thereafter decreasing to 1349.53 Gl/year in 2040, a fall of 63% in 43 years. The OPEC and non-OPEC oil production curves are also shown for comparison to world production curve. The cross-over point when OPEC production exceeded non-OPEC production was in the year 2007 [21–24].

As of January 1, 2008, the proved world oil reserves were estimated at 156,296.88 bl. Middle East with 87,777.8 Gl (57%) and Europe with 1642.9 Gl (1%) are the maximum and minimum oil reserve regions, respectively. Considering the rate of oil production and consumption, one can say that the oil reserves may run out as long as for the coming three to four decades. It is therefore inevitable to find the suitable and sustainable replacement [25].

Table 1 shows the world oil reserves by countries as of January 1, 2008. The first three positions belong to Saudi Arabia, Canada and Iran. Out of the World total of 156,275 bl reserved oil, 148,025.3 bl is the share of 20 countries and only 70.3 billion barrels belongs to rest of the world. Table 1 indicates that the world oil reserves are highly concentrated in Middle East with 57% of the total oil reserves [25].

Table 1
World oil reserves by country.

S. no.	Country	Oil reserves	S. no.	Country	Oil reserves
1	Saudi Arabia	31,015.6	12	United States	2464.4
2	Canada	20,958.7	13	China	1877.6
3	Iran	16,241.2	14	Qatar	1783.7
4	Iraq	13,495.3	15	Algeria	1431.7
5	Kuwait	11,911	16	Brazil	1431.7
6	UAE	11,476.8	17	Mexico	1373
7	Venezuela	10,209.5	18	Angola	1056.2
8	Russia	7,041	19	Azerbaijan	821.5
9	Libya	4,870	20	Norway	809.7
10	Nigeria	4,248.1	21	Rest of the World	8249.7
11	Kazakhstan	3.520.5	–	–	–
World total = 156,286.7 (**Billion liters**)					

3. Oil reserves and forecast for Iran

Iran has enormous reserves of oil and natural gas. Oil reserves are estimated at about 16,241.24 bl, about 11% of world proven reserves, and natural gas reserves are estimated at about 32 trillion cubic meters, second in the world [25]. Oil industry output averaged about 469.4 million liters per day in 2005 and 2006, compared with the peak output of 774.5 million liters per day reached in 1976. The second peak production starts somewhere around the year 2010. From the year of peak onwards, the production trend starts falling, though the faster you pump, the sooner you reach peak production and finally reach the oil depletion. There is no doubt that the end of the oil era for Iran is estimated to be slightly more than the double of the average estimation for world taken as a whole, but it is important to note that Iran is also part of the world's society and moreover an importer of the a oil derivatives such as diesel and gasoline fuels. Iran is also compelled to look for renewable and sustainable energy sources especially the liquid biofuel for transportation.

4. World's liquid biofuels outlook

The humanity's top ten challenges for next 50 years can be summarized as: energy, water, food, environment, poverty, terrorism, war, disease, education, democracy, and population. It is obvious that with human population growth during the coming century, energy is one of the priorities associated with the other vital and essential needs such as food and water. Increase in energy demand is both necessary for development and fulfillment of population growth specially in the case of developing regions. About 3 billion increase in the world population during this century, needs energy for living and to move the development wheel in all sectors. On the other hand, fossil fuel depletion and environmental consequences of using fossil fuels are the two major reasons for compelling the world towards the renewable biofuels especially liquid ones due to their easy production, transportation and application. The interest in biofuels can be mostly attributed to the cited advantages as follow:

- Biofuels reduce the emission of gasses responsible for global warming,
- Biofuels promote rural development,
- Biofuels contribute towards the energy security of countries,
- Biofuels are renewable,
- Biofuels reduce pollution, and finally
- Biofuel blends can be used without major modifications to engines currently in use. Production and consumption of biofuels have increased sharply since 2003. In most countries the diesel fuel used contains biodiesel, at least in low blends. Production capacity keeps growing and car manufacturers started to market cars that can run on high bioethanol blends. The data available indicates that liquid biofuels were being used in 21 EU countries out of 25 by the year 2005, with an

estimated market share of 1%. The approximate breakdown of biofuels in the EU for the 2002–2005 periods was 76% biodiesel and 24% ethanol [26,27]. Given the growing interest in biofuels as an alternative fuel source, many countries are promoting biofuels use through directives and/or mandates. A few European countries such as Austria, Germany, and France took interest in biofuels during the 1990s but serious promotion for biofuels production appeared by approval of the 2003/30/EC and 2003/96/EC directives. The 2003/30/EC directive targeted the use of biofuels and other renewable fuels for transportation. The fuel directive includes not only a reference target of 5.75% of market share for biofuels by 2010 but also recommends that member countries set an interim target of 2% for 2005. Tables 2 and 3 show the biofuels blending targets for selected countries and the indicative targets set for biofuels from 2005 through 2010 by EU25. The guideline targets, however, were not mandatory and that might be the reason for most of the countries set intended values below 2% for 2005. It is also important to note that the directive referred only to market share and not to production. Therefore, each country could import biofuels to comply with the directive [28].

The Energy Independence and Security Act (EISA) was signed into law in December 2007 in USA that includes a number of provisions to encourage or require the use of biofuels, and these are incorporated in the baseline projections. The overall renewable fuel standard (RFS) requires that 9 billion gallons of biofuels be utilized in calendar year 2008, growing to 24 billion gallons by 2017 and more in later years [29].

Brazil pioneered the production of liquid biofuels well before World War II, using parts of its vast sugar cane plantations for the production of what is known as bioethanol. The second major producer of bioethanol after Brazil (up to 2006) was the United States, starting its production of bioethanol from maize in the 1980s. These producers consume the whole of their own biofuel production internally. In 2007, the annual world total production of bioethanol was approximately 1525.6 billion liters.

Biodiesel has recently experienced a major surge worldwide. A rapid expansion in production capacity is being observed not only in developed countries like Germany, Italy, France, and the United States but also in developing countries like Brazil, Argentina, Indonesia, and Malaysia [28].

5. Iran's liquid biofuels potential and outlook

The Islamic Republic of Iran is located in the Middle East, between Turkey and Iraq on the west and Afghanistan and Pakistan on the east; it borders the Persian Gulf and Gulf of Oman in the south and Armenia, Azerbaijan, the Caspian Sea, and Turkmenistan in the north with a land area of about 1648,000 square kilometers. Iran's coastline includes 2440 km on the Persian Gulf and Gulf of Oman and 740 km on the Caspian Sea. The major rivers in Iran are Karun, which is 830 km long, the Safid Rud (1000 km), Karkheh (700 km), and Zayandeh Rud (400 km). Iran's climate is mostly arid and semi-arid, with a humid rain-forest zone along the Caspian coast. The average temperature is 10–25 °C in the winter and 19–38 °C in the summer. Table 4 shows the details of total land area including forest land and

Table 3
Targets for the share of biofuels by EU members (in %).

Member state	2005	2006	2007	2008	2009	2010
Austria	2.5	2.5	4.3	7.75	5.75	5.75
Belgium	2	2.75	3.5	4.25	5	5.75
Cyprus	1	–	–	–	–	–
Czech Rep.	3.7	1.75	1.63	2.45	2.71	3.25
Denmark	0.1	0.1	–	–	–	–
Estonia	2	2	–	–	–	5.75
Finland	0.1	–	–	–	–	–
France	2	–	–	5.75	–	7
Germany	2	2	–	–	–	5.75
Greece	0.7	2.5	3	4	5	5.75
Hungary	0.6	–	–	–	–	5.75
Ireland	0.06	11.14	1.75	2.24	–	–
Italy	1	2	2	3	4	5
Latvia	2	2.75	3.5	4.25	5	5.75
Lithuania	2	–	–	–	–	5.75
Luxemburg	0	2.75	–	–	–	5.75
Malta	0.3	–	–	–	–	–
The Netherlands	2	2	2	–	–	5.75
Poland	0.5	1.5	2.3	–	–	5.75
Portugal	2	2	3	5.75	5.75	5.75
Slovakia	2	2.5	3.2	4	4.9	5.75
Slovenia	0.65	1.2	2	3	4	5
Spain	2	–	–	–	–	–
Sweden	3	–	–	–	–	5.75
UK	0.19	–	–	2	2.8	3.5
EU	**1.4**	**–**	**–**	**–**	**–**	**5.45**

Table 2
Liquid biofuel production and blending targets for selected countries.

Country	Feedstocks		2007 production (million liters)		Blending targets
	Ethanol	Biodiesel	Ethanol	Biodiesel	
Brazil	Sugarcane, soybeans, palm oil	Castor seed	18,798.2	242.6	25% blending ratio of ethanol with gasoline (E25) in 2007; 2%blend of biodiesel with diesel (B2) in early 2008, 5% by 2013.
Canada	Corn, wheat, straw	Animal fat, vegetable oils	1,000.0	96.1	5% ethanol content in gasoline by 2010; 2%biodiesel in diesel by 2012.
China	Corn, wheat, cassava, sweet sorghum	Used and imported vegetable oils, jatropha	1,599.9	113.2	Five provinces use 10% ethanol blend with gasoline; five more provinces targeted for expanded use.
EU	Wheat, other grains, sugar beets, wine, alcohol	Rapeseed, sunflower, soybeans	2,302.8	6555.2	5.75% biofuel share of transportation fuel by 2010, 10% by 2020.
India	Molasses, sugarcane	Jatropha, imported palm oil	400.1	45.4	10% blending of ethanol in gasoline by late 2008, 5%biodiesel blend by 2012.
Indonesia	Sugarcane, cassava	Palm oil, jatropha	–	407.6	10% biofuel by 2010.
Malaysia	None	Palm oil	–	328.5	5% biodiesel blend used in public vehicles; government plans to mandate B5 in diesel-consuming vehicles and in industry in the near future.
Thailand	Molasses, cassava, sugarcane	Palm oil, used vegetable oil	300.2	260.4	Plans call for E10 consumption to double by 2011 through use of price incentives; palm oil production will be increased to replace 10%of total diesel demand by 2012.
United States	Primarily corn	Soybeans, other oilseeds, animal fats, recycled fats and oil	24,597.6	1682.4	Use of 7.5 billion gallons of biofuels by 2012; proposals to raise renewable fuel standard to 36 billion gallons (mostly from corn and cellulose) by 2022.

water bodies, a substantial potential for cultivation of both energy inland and aquatic plants and biofuels feedstock.

Considering the existing resources such as land and water body areas in Iran, interests on expansion of biofuels production and application could be speeded up through mandates and financial incentives by Iranian government similar to the other countries. Research interest in liquid biofuels has grown strongly due to the steep climb in fossil fuel oil prices and import of petroleum derivatives such as diesel and gasoline fuels during recent years [30–46] and also the enactment of stringent environmental laws and regulations regarding the transportation exhaust pollutions. Biofuels could provide Iranian nation with a means to invest in natural renewable resources instead of exporting its capital to purchase fossil fuel products such as gasoline and diesel fuels (requiring 9 billion US dollar for the fiscal year of 2008). Production and consumption of liquid biofuels would also contribute significantly to mitigating global warming, creating jobs and encouraging agriculture sector. This is necessary to be planned from resources to end use (Fig. 1). This means that Iran has to plan from bioenergy farms to biorefineries and finally bringing the biofuels to the petrol stations.

Iran's diversity of terrain and climate enables cultivation of energy a variety of crops suitable for liquid biofuels production. Iranians grow a variety of crops, most notably wheat, barley, rice, pistachio nuts, cotton, sugar beets, and sugar cane, a primary source of bioethanol feedstock. About one-third of agricultural income comes from feedstock, chiefly chickens, sheep, beef cattle, and dairy cows, a notable source for animal fats as biodiesel feedstock.

Table 4
Total area of Iran including forest land and water bodies.

FRA 2005 categories	Area (1000 hectares)		
	1990	2000	2005
Forest	11,075	11,075	11,075
Other wooded land	5,340	5,340	5,340
Forest and other wooded land	16,415	16,415	16,415
Other land	147,205	147,205	147,205
… Of which with tree cover	83	83	83
Total land area	163,620	163,620	163,620
Inland water bodies	1,200	1,200	1,200
Total area country	164,820	164,820	164,820



Fig. 1. Biofuels from feedstock to end use.

Table 5 shows the potential production of bioethanol from agricultural wastes. In Iran, the easily and readily available leading biofuels feedstock today for production of bioethanl are sugar cane and sugar beet molasses which is estimated to be about 500 million liters. The available produced molasses is partially exported and partially processed to produce alcohol which is used for medical and industrial purposes. Molasses can be processed to yield fuel grade bioethanol that can be blended into gasoline. Sugarcane requires good land and large amounts of irrigation water, which is present in Khuzestan Province, South of Iran, mainly due to the presence of rivers such as Karun River and also flat fertile lands.

In Iran, agricultural residues are not commonly used for energy production purposes. Crop residues and sugar cane bagasse can be included in feedstock for production of fuel grade bioethanol. There is approximately 17.86 million tons of wasted crops in Iran that can potentially produce 4.91 billion liter of bioethanol annually. Wheat, sugar cane bagasse, rice, barely and corn are the most favorable bioethanol production source in Iran.

About one third of Iran's total land area can be utilized to produce crops provided sufficient water is available. However, only 12% of the total land area is currently under cultivation. The total production of wheat, corn, rice and barley has rapidly increased. This increase is attributed to a combination of higher yields and extension of the area under cultivation. In the years of 2007 and 2008, the total production of field crops was at a record of 22.0 million tons, marginally higher than 2006–2007.

Fortunately several varieties of biomass resource are available in Iran that include: animal waste, urban waste, urban waste from waste water, industrial waste, agricultural residues, forest residues and wood wastes, though the exact quantity is yet to be declared from two ongoing feasibility study projects results.

As mentioned in Iran, biofuels has great potential to improve energy services based on agricultural residues. Various agricultural residues such as wheat straw, rice straw and husk, corn stalk and cob, barely straw and sugar cane bagasse are produced and disposed. The available agricultural residues in Iran has been estimated to be 17–20% of total production of crops [47]. The conversion of agricultural wastes into useful bioenergy and especially liquid biofuels has already started in small scales in Iran for research and technology development purposes [30–46]. The data for biomass and crop residues for bioethanol production are obtained from FAO statistics (FAOSTAT) and also agricultural ministry of Iran [48]. As it was explained, Table 5 shows the potential of bioethanol production from wastes of 10 agricultural crops. These 10 products are wheat, sugar cane, rice, barely potato, date, sugar beet, grape and apple. These agricultural waste materials could be converted to useful liquid biofuels.

Approximately 50% of wheat is lost as waste. The amount of wheat production is about 15 million tons. The utilization of the

Table 5
Potentioal of bioethanol (billion liters) from agricultural wastes in Iran.

Crop	Production (million ton)	Residual percentage (%)	Wastes (million ton)	Conversion factor (L/ton)	Total bioethanol (Bill.lit.)
Wheat	15	50	7.5	400	3
Sugar cane molasses	4&0.3	100	4&0.3	135 and 300	0.63
Rice	2	25	0.5	400	0.2
Barley	3	20	0.6	350	0.21
Corn	3.5	30	1.05	360	0.378
Potato	5	30	1.5	110	0.165
Date	0.9	40	0.36	360	0.129
Sugar beet molasses	.25	100	0.25	300	0.075
Grape	3	30	0.9	70	0.063
Apple	3	30	0.9	65	0.0585
Total	**39.95**		**17.86**		**4.91**

waste from the wheat can produce 3 billion liters of bioethanol per annum. The annual gasoline consumption is 24 billion liter as reported in the year 2008. A blend of E5 is under study to be implemented in Ahwaz city of Khuzestan province in the year of 2011. In comparison to other conventional fuel, bioethanol can be an optimum alternative fuel for spark ignition engine vehicles [49].

At least 4.3 million tons of bagasse from sugar cane is produced in Iran annually. The Khuzestan province is the unique province in Iran's sugar cane production. Approximately 30% of total rice production is also lost as waste. A 1.05 million tons of rice waste could efficiently produce 378 million liters of bioethanol [47].

Iran has about 7% of its area covered with forest. The major commercially useful forests are located in the Alborz Mountains in the north, especially on the southern slopes above the Caspian Sea coast. Smaller forests, principally of oak and other deciduous trees, are scattered throughout the Zagros Mountains in western and central Iran. Iran is a net importer of timber products. In 2003, the timber industry produced about 13 million cubic meters of wood products, of which about 37% was pulpwood and 24% logs. These forest products are good sources for both bioethanol and biodiesel production. Iran is also suitable for other bioethanol feedstock plantations such as algae and forest (Fig. 2).

Iran has a long tradition of fishing in the Caspian Sea, in the Persian Gulf, and on inland rivers. The government company Sheelat establishes fishing quotas and buys fish for processing. Most of the actual fishing is undertaken by small-scale, private fishermen, though the most economically important product of the fishing industry is Caviar from Caspian Sea sturgeon. Iran has an aggressive fish nurseries program aimed at reversing the decline in Caspian fish stocks. Other products of the fishing industry are tuna, the sardine-like kilka, trout, and shrimp. In 2004 catches totaled about 330,000 t of fish. The fish oil could be a suitable feedstock for biodiesel production in Iran; its actual potential is under investigation. Iran is also suitable for other biodiesel feedstock plantations such as palm tree, Jatropha, castor plant and algae (Fig. 3).

As a concluding paragraph in this paper, about 4.91 billion liters of bioethanol can be produced from the crop wastes. The future bioethanol production in Iran can be an optimum alternative fuel for spark ignition engines using gasohol in different blend ratios as a forecast up to 2026 (Fig. 4 and Table 6).

As far as biodiesel production is concerned, there is a noticeable quantity of edible cooking oil waste in Iran (about 20% of the 1.5 million tons of consumption) that can be converted to

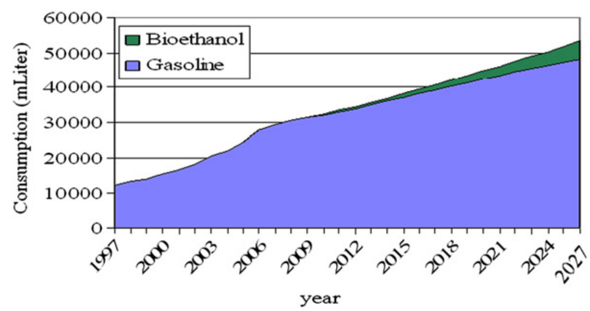


Fig. 4. Gasoline bioethanol blending forecasts for Iran.



Fig. 2. The potential regions of bioethanol feedstock in Iran.



Fig. 3. The potential regions of oil production as biodiesel feedstock in Iran.

Table 6
The outlook of liquid biofuels share in Iran's transportation.

Year	Bioethanol			Biodiesel		
	Blends	(million liters)	(mboe)	Blends	(million liters)	(mboe)
2010	E1	324	1.12	B0	0	0
2011	E1	334	1.16	B0	0	0
2012	E2	692	2.39	B1	239	1.30
2013	E2	713	2.46	B1	250	1.36
2014	E2	737	2.55	B1	262	1.42
2015	E3	1146	3.96	B2	549	2.98
2016	E3	1184	4.09	B2	575	3.13
2017	E4	1633	5.64	B2	602	3.27
2018	E4	1683	5.82	B3	948	5.15
2019	E5	2174	7.51	B3	993	5.40
2020	E5	2237	7.73	B4	1388	7.55
2021	E6	2769	9.57	B5	1820	9.89
2022	E7	2845	9.83	B6	2290	12.45
2023	E8	3421	11.82	B7	2803	15.23
2024	E8	4027	13.91	B8	3360	18.26
2025	E9	4664	16.12	B9	3965	21.55
2026	E10	5333	18.43	B10	4622	25.12

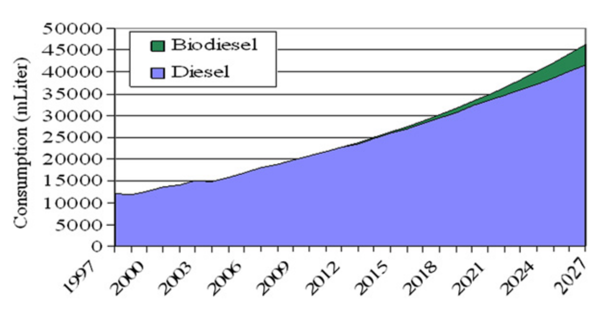


Fig. 5. Diesel- biodiesel blending forecasts for Iran.

biodiesel easily. This amount along with the existing potentials is quite enough to forecast blending ratios up to B10 by the year 2026 (Fig. 5 and Table 6), though there is a need for more research and development on renewable energy crops. There are two ongoing national projects on feasibility studies of liquid baiofuel (bioethanol and biodiesel) in this regard, the final results of which will be available in near future. These projects are being carried out by Tarbiat Modares University (TMU) with the cooperation of Iranian Fuel Conservation Organization (IFCO). The initial results of these projects are now available, which are very much embracing and show an encouraging potential for liquid biofuels (bioethanol and biodiesel) production and outlook in Iran.

Acknowledgements

The author would like to thank the Iranian Fuel Conservation Organization (IFCO) of National Iranian Oil Company (N.I.O.C.) for the research grant provided to carry out this investigation.

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